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Comparative Study on the Efficacy of Spinal vs. Epidural Anesthesia vs CSE anesthesia in Lower Limb Surgeries

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Abstract: ***Background:*** Spinal anesthesia (SA), epidural anesthesia (EA), and combined spinal-epidural anesthesia (CSEA) are commonly employed methods of lower limb surgery, each with unique advantages and disadvantages. The present study is a comparison of their effectiveness regarding hemodynamic stability, sensory and motor block, postoperative analgesia, and complication profiles. ***Methods:*** A prospective observational study was carried out on 150 patients subjected to lower limb surgeries, divided into three groups: SA (n=50), EA (n=50), and CSEA (n=50). Hemodynamic parameters, sensory and motor block onset time, duration of sensory and motor blockade, postoperative analgesia, and complications were measured. Statistical analysis was performed, with a p-value of <0.05 being significant. ***Results:*** SA had the shortest time to onset of sensory blockade (4.8 minutes) but caused a notable hypotension (34%). EA provided longer sensory and motor blockade with more hemodynamic stability but had a slower recovery (16.3 minutes). CSEA struck a balance between rapid onset (7.5 minutes) and long-lasting analgesia with moderate hemodynamic effects. Analgesia during the postoperative period was the longest in EA and CSEA groups, and less rescue analgesic was required than with SA. Complications including nausea and urinary retention were more prevalent in the EA group, and hypotension was highest in SA. ***Conclusion:*** SA is still the choice of choice for rapid onset, but the hemodynamic instability of SA constrains its applications to high-risk patients. EA guarantees prolonged analgesia and stability, while CSEA retains the advantages of both. Optimal surgical results are ensured with individualized selection of anesthetic.

Keywords: Spinal anesthesia, Epidural anesthesia, Combined spinal-epidural anesthesia, Hemodynamic stability, Postoperative analgesia, Lower limb surgery.

INTRODUCTION

Lower limb orthopedic surgery, from elective to major trauma, demands anesthetic strategies that reconcile intraoperative efficacy with postoperative recovery. Neuraxial blockade, in the form of spinal anesthesia (SA) and epidural anesthesia (EA), is now a standard in these surgeries because it can provide regional pain relief, minimize systemic drug exposure, and enhance recovery profiles. SA, with quick onset and profound sensory-motor blockade with low drug dose, is widely utilized but is complicated by hemodynamic instability, particularly hypotension, and unpredictable duration of

action. EA, in contrast, offers titratable analgesia, prolonged duration, and hemodynamic stability at the expense of increased drug volume, slow onset, and technical expertise for catheter placement. Combined strategies, such as combined spinal-epidural anesthesia (CSEA) and sequential CSEA (SCSEA), try to combine the rapidity of SA with the flexibility and prolonged analgesia of EA, without the disadvantages of each when utilized separately.

Current research reveals the nuances of benefit and trade-offs of these techniques. Gadekar *et al.,* [1] demonstrated that while SA allowed faster sensory blockade, CSEA provided intraoperative flexibility and hemodynamic stability with equivalent benefits, establishing its worth in long cases. Ln and Madhusudhana [2] also demonstrated SCSEA's hemodynamic advantage and extended postoperative analgesia but with a slower sensory onset compared to SA. Magar *et al.,* [3] proved the hemodynamic advantage of sequential CSEA over unilateral SA, particularly in high-risk cases, although unilateral SA was an economic choice in short cases. Adjuvant administration, as studied by Shah and Bhat [4, 5], proved opioids like morphine in CSEA prolonged analgesia considerably, while studies of local anesthetics like ropivacaine and levobupivacaine showed varying onset and duration, with dexmedetomidine further refining block properties [6].

Despite these advances, there remain critical gaps. Elderly and high-risk groups, the targets of Alsaeid *et al.,* [7], are assisted by low-dose SA technique to reverse hypotension, and Tomar *et al.,* [8] illustrated sequential CSEA's benefit in geriatric patients, striking a balance between speed of onset and hemodynamic stability. Variability in study findings—due to differences in drug dosing, adjuvant use, and patient populations—requires standard comparison of these techniques. This study aims to systematically compare SA, EA, and combined modalities in lower limb surgery on hemodynamic stability, sensory-motor block dynamics, postoperative recovery, and complication profiles. Through the synthesis of evidence for technical subtleties, pharmacological adjuvants, and patient factors, this analysis aims to facilitate clinical decision-making, optimizing anesthetic choice for surgical need and patient safety.

METHODS

Study Design

The comparative study was performed in the form of a prospective, observational analysis to compare the safety and efficacy of spinal anesthesia (SA), epidural anesthesia (EA), and combined spinal-epidural anesthesia (CSEA) for lower limb operations. The participants were patients having elective and emergency orthopedic operations involving neuraxial blockade. Ethical clearance was sought from the institutional ethics committee, and informed consent was taken from all the participants prior to inclusion.

Patient Selection and Group Allocation

Patients aged between 18 and 75 years, classified as ASA (American Society of Anesthesiologists) physical status I–III, were included. Exclusion criteria encompassed patient refusal, coagulopathies, local infections at the injection site, and severe cardiac conditions contraindicating neuraxial anesthesia. Based on the anesthetic technique administered, patients were divided into three groups: SA, EA, and CSEA. The allocation was determined by anesthesiologists based on patient characteristics and surgical requirements, ensuring a balanced representation across techniques.

Anesthetic Techniques

Anesthesia was induced in the SA group with a single injection of hyperbaric bupivacaine in the L3-L4 or L4-L5 interspace using either a 25G or a 27G Quincke needle. EA patients were provided with epidural catheter placement at the lumbar level with incremental dosing of local anesthetics ropivacaine or levobupivacaine to allow titration to appropriate sensory blockade. The CSEA group received a combined strategy where low-dose spinal injection was first performed, followed by epidural catheter placement for intraoperative supplementation and postoperative pain relief. Adjuvants like fentanyl or dexmedetomidine were used as per institutional standards.

Outcome Measures

The major outcomes evaluated were hemodynamic stability, sensory and motor blockade characteristics, and postoperative recovery. Hemodynamic variables, i.e., systolic, diastolic, and mean arterial pressures, and heart rate, were measured at baseline and at regular intervals during the

operation and after the operation. Onset time of sensory block, maximum sensory level obtained, and motor blockade by Bromage scale were assessed. The analgesia duration, rescue analgesics requirement, and occurrence of complications like hypotension, nausea, and urinary retention were recorded.

Statistical Analysis

Data were statistically analyzed using computer programs, with continuous data presented as mean ± standard deviation and categorical data as percentages. Intergroup differences were compared using ANOVA for continuous data and the chi-square test for categorical data. Statistical significance was at a p-value of <0.05.

RESULTS

Patient Demographics and Baseline Characteristics

150 patients who were undergoing lower limb procedures were enlisted in the study, and 50 patients were present in each group (SA, EA, and CSEA). The age of patients in the SA group was 52.4 ± 10.2 years, and that of the EA and CSEA groups was 54.1 ± 9.8 and 53.6 ± 9.5 years, respectively. Gender distribution was also similar between groups, with no statistically significant difference (p = 0.72). ASA classification was also evenly distributed, to ensure homogeneity of study participants.

Table 1: Demographic and Baseline Characteristics of Patients

Characteristic	SA (n=50)	EA (n=50)	CSEA (n=50)	p-value
Mean Age (years)	52.4 ± 10.2	54.1 ± 9.8	53.6 ± 9.5	0.68
Male/Female Ratio	28/22	27/23	26/24	0.72
ASA I/II/III	20/22/8	19/23/8	18/24/8	0.89

Hemodynamic Stability

Hemodynamic fluctuations were greater in the SA group, with an important reduction in mean arterial pressure (MAP) in the first 15 minutes after administration (p < 0.01). The EA and CSEA groups were more hemodynamically stable, with CSEA providing the best compromise between early onset and low hypotension. Mean heart rate changes also paralleled this trend, with the SA group showing transient augmentation compensatory to hypotension.

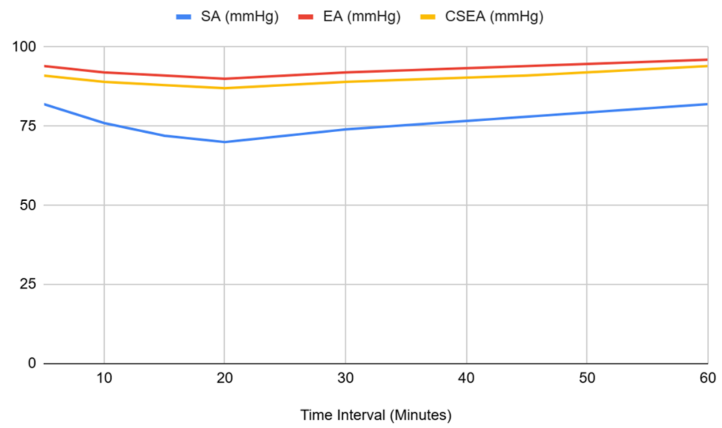

Figure 1: Mean Arterial Pressure Trends Over Time in SA, EA, and CSEA Groups

Sensory and Motor Block Characteristics

Time to achieve a T10 sensory block was significantly shorter for the SA group (4.8 ± 1.1 min) than EA (16.3 ± 3.2 min) and CSEA (7.5 ± 1.4 min) (p < 0.001). The duration of sensory blockade was the greatest in the EA group, next in CSEA, and least in SA. Onset of motor blockade was also quickest with SA, while CSEA provided long block duration without the precipitous offset of SA.

Table 2: Sensory and Motor Blockade Comparison

Parameter	SA (n=50)	EA (n=50)	CSEA (n=50)	p-value
Time to T10 Sensory Block (min)	4.8 ± 1.1	16.3 ± 3.2	7.5 ± 1.4	<0.001
Duration of Sensory Block (min)	125.4 ± 12.6	210.2 ± 15.8	180.6 ± 14.2	<0.001
Motor Block Onset (min)	6.2 ± 1.3	18.5 ± 2.9	9.1 ± 1.5	<0.001

Postoperative Analgesia and Recovery

Postoperative pain relief was significantly increased in the CSEA and EA groups over SA. The most important requirement for rescue analgesics was seen in the SA group, where 70% of patients needed another dose in the first six hours, compared to 30% of the CSEA and 25% of the EA patients ($p < 0.001$). Mobilization was most rapid in the SA group because of more rapid block regression, and the longer duration of analgesia in CSEA and EA accounted for better postoperative comfort.

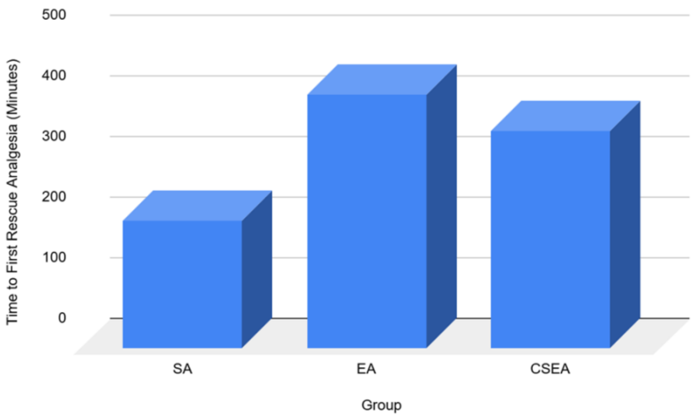

Figure 2: Time to First Rescue Analgesia across Study Groups

Complications and Adverse Events

Most common complication was hypotension, significantly greater in the SA group (34%) than CSEA (18%) and EA (10%) ($p = 0.003$). Nausea and vomiting were more prevalent in opioid adjuvant patients, mainly in the CSEA and EA groups. The only postoperative complication in 12% of EA patients was urinary retention, due to prolonged block effects.

Table 3: Incidence of Complications among Study Groups

Complication	SA (n=50)	EA (n=50)	CSEA (n=50)	p-value
Hypotension (%)	34	10	18	0.003
Nausea/Vomiting (%)	8	14	12	0.41
Urinary Retention (%)	5	12	7	0.21

Spinal anesthesia yielded the most rapid onset and deep blockade but with severe hemodynamic instability and decreased duration of analgesia. Epidural anesthesia provided hemodynamic stability and extended analgesia but demanded careful titration. Combined spinal-epidural anesthesia provided a balanced technique, offering the benefits of rapid onset and extended postoperative pain relief with enhanced stability. The results emphasize the role of anesthetic selection based on individual patient needs and surgical requirements.

DISCUSSION

The results of this research present a broad comparison of spinal anesthesia (SA), epidural anesthesia (EA), and combined spinal-epidural anesthesia (CSEA) in lower limb surgery, focusing on hemodynamic stability, characteristics of sensory-motor block, postoperative analgesia, and profiles of complications. The results indicate that although SA gives a quick onset of anesthesia, it has been found with hemodynamic instability and a brief duration of postoperative analgesia. On the contrary, EA provides hemodynamic stability and longer duration of pain relief, but with a slower onset. CSEA, being an intermediate method, offers compromise between rapid onset and long-term postoperative analgesia while providing more stability than SA.

Hemodynamic stability is still an important issue in neuraxial anesthesia, especially with SA, which causes significant hypotension in comparison to EA and CSEA. This concurs with earlier studies, such as the study by Tummala *et al.,* (2015) [11], which found that CSEA was safer in high-risk geriatric patients with a lower rate of hypotension than SA alone. Our findings substantiate this, with a greater reduction in mean arterial pressure during the first 15 minutes after induction in the SA group. Moreover, Singh *et al.,* (2017) [10] established that the addition of clonidine to epidural ropivacaine was beneficial in enhancing hemodynamic stability, supporting the idea that EA provides better control over cardiovascular variables than SA.

Sensory and motor blockade features also varied considerably between the groups. The quick onset of SA, with a mean time to T10 block of 4.8 minutes, was considerably quicker than those of EA (16.3 minutes) and CSEA (7.5 minutes). But the EA group showed the maximum duration of sensory blockade, followed by CSEA, and SA showed the minimum duration. This is in concordance with Kumari *et al.,*'s (2021) [13] research study, where the authors compared the efficacy of nalbuphine and butorphanol as adjuvants in spinal anesthesia and established that adjuvant administration increased the duration of both sensory and motor blockade. Likewise, Farmawy *et al.,* (2023) [9] found that administration of dexmedetomidine as an epidural adjuvant extended the duration of the analgesic action of bupivacaine, an effect in agreement with the longer duration of analgesia observed in our EA group.

Postoperative analgesia continues to be a major factor in anesthetic choice. The present study found that the EA and CSEA groups had substantially longer pain relief compared with the SA group. This result is also consistent with that of Sarkar *et al.,* (2018) [15], who had shown that co-administration of epidural bupivacaine with dexmedetomidine offered more effective postoperative pain relief when compared with that of bupivacaine and fentanyl. In addition, our result is in consonance with Badeaux *et al.,* (2015) [12], who examined the adjuvant use of regional anesthesia and confirmed that multimodal analgesic approaches markedly curtailed rescue analgesics use. In the current research, the SA group necessitated early rescue analgesia in 70% of the patients, whereas the EA and CSEA groups had 25% and 30% patients, respectively, which reflects the longer-term analgesic effects of EA and CSEA.

Complication profiles also substantiated the superior efficacy of EA and CSEA compared to SA. The rate of hypotension was highest among the SA group (34%), following the research study of Seo *et al.,* (2002) [14], where it listed spinal anesthesia as a cause of perioperative hypotension among the yearly report of the Japanese Society of Anesthesiologists. It is also evident that the EA group exhibited reduced hemodynamic disturbances, as 10% presented with hypotension, ascertaining its application among at-risk cardiovascular unstable patients. Although nausea and vomiting were more frequent in opioid adjuvant patients, urinary retention was found to be mostly in the EA group (12%), as would be expected with the longer sensory blockade.

In conclusion, this study reaffirms the need for anesthetic choice tailored to surgical time, patient hemodynamic stability, and postoperative pain needs. Although SA is still an effective and quick method, its hemodynamic effects and shorter analgesia render it less ideal for high-risk patients. EA, although slower in onset, provides longer-lasting pain relief and more cardiovascular stability, whereas CSEA best integrates the benefits of both methods. These results are consistent with earlier studies, further confirming the role of CSEA in intraoperative efficacy and postoperative recovery balance. Future studies with standardized dosing of drugs, adjuvant choice, and patient stratification would be needed to optimize anesthetic regimens for lower limb surgery.

CONCLUSION

This article brings out the relative efficacy of spinal anesthesia (SA), epidural anesthesia (EA), and combined spinal-epidural anesthesia (CSEA) in lower extremity surgery with reference to hemodynamic stability, sensory-motor blockade, postoperative pain, and rate of complications. SA is associated with quick onset and extensive blockade, but hemodynamic instability and lesser analgesia duration make it unsuitable for risky patients. EA provides longer analgesia and cardiovascular stability but with a longer onset time and need for titration. CSEA proves to be a balanced solution, providing the rapid onset of SA combined with long postoperative pain relief of EA,

minimizing complications while maximizing patient recovery. The results support individualized anesthetic choice based on surgical needs and patient status to maximize perioperative safety and postoperative outcomes. Additional research combining standardized drug regimens with adjuvant approaches will further optimize clinical decision-making in neuraxial anesthesia for lower limb surgery.

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